

WAMS measurements pre-processing for detecting low-frequency oscillations in power systems

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Abstract. Processing the data received from measurement systems implies the situation when one or more registered values stand apart from the sample collection. These values are referred to as “outliers”. The processing results may be influenced significantly by the presence of those in the data sample under consideration. In order to ensure the accuracy of low-frequency oscillations detection in power systems the corresponding algorithm has been developed for the outliers detection and elimination. The algorithm is based on the concept of the irregular component of measurement signal. This component comprises measurement errors and is assumed to be Gauss-distributed random. The median filtering is employed to detect the values lying outside the range of the normally distributed measurement error on the basis of a 3σ criterion. The algorithm has been validated involving simulated signals and WAMS data as well.

1. Introduction

It is common knowledge that the essential source of information on the power system equipment current operation state is the combination of the equipment performance parameters measurements. At the same time measurements validity i.e. degree of belief is defined by these measurements accuracy [1, 2]. To date large-scale power systems impose strict requirements on measurement systems accuracy for the purposes of monitoring and improving stability, controllability and security [3–5]. Wide-area monitoring systems (WAMS) based on phasor measurements technology have been implemented in many power systems in order to meet these requirements [6].

Nevertheless there are errors inherent in WAMS data inevitably. These errors may be due to various causes including measurement errors of instrument transformers, secondary circuits and Phasor measurement units (PMUs), data transfer failures etc. [7]. These reasons may lead to emerging outliers [8] i.e. values standing apart from the sample collection. While it is unlikely that instrument transformers and secondary circuits measurement errors would change rapidly over time it is still typical for PMU themselves to cause outliers during transients which is proved by the corresponding research [9–11].

This particular feature influences significantly the low-frequency oscillations (LFO) express-analysis (detecting and estimating parameters) performance capability [12]. It is of crucial importance to pinpoint outliers in WAMS data received online and correct them without making unnecessary and undesired changes to surrounding data.



2. Outliers elimination algorithm

The corresponding algorithm has been developed for the purpose of locating the outliers. It is necessary to define the maximum duration or number of data points considered to be the outlier. The outlier duration is subject to WAMS data sampling rate. For example in case the sampling rate is 50 Hz i.e. 1 measurement point per every 0.02 s and LFO of 5 Hz frequency arise the oscillations half-period is 5 points long. As the algorithm is aimed at preserving the oscillations data it is recommended to set the outlier maximum duration equal to 4 points. Nevertheless this parameter could be adjusted depending upon the field of application.

The median filter has been selected to be utilized within the algorithm due to its capability to leave the data points of the signal being processed unaltered in case the outlier duration does not exceed the half of the window width. This is a significant advantage compared to smoothing filtering, which alters all data points.

First, median filter is applied to the data $x(i)$ under consideration with filter window defined as $2n + 1$ where n is the predefined maximum outlier duration:

$$x(i) \rightarrow m(i). \quad (1)$$

After that the filtering result $m(i)$ is subtracted from the initial data:

$$d(i) = x(i) - m(i), \quad (2)$$

and standard deviation σ_m is calculated for the obtained difference:

$$\sigma_m = \sqrt{\frac{1}{k-1} \sum_{j=n-k}^{n-1} (d_i - \bar{d})^2}, \quad (3)$$

where \bar{d} is the expected value of $d(i)$ within the $[n-k; n-1]$ interval.

According to equation (3), the standard deviation σ_m is calculated not for the whole sample collection but at every sequential point of it. This allows for time variations of non-regular component of the signal.

Then all points where absolute $d(i)$ values exceed $\bar{d} + 3\sigma_m$ are considered to be outliers and replaced by linear sections. This approach is reasonable when equipment measurement errors distribution is close to Gaussian which is correct for currently employed PMUs [4].

3. Algorithm experimental validation

The algorithm is validated using MATLAB software package. The validation involves simulated signals and actual WAMS data.

3.1. Validation using simulated data

In order to prove the algorithm effectiveness it has been validated using complex harmonic noise-contaminated signal with artificially added outliers:

$$0.3 \sin(0.05t) + \sin(1.3 \times 0.05t) + 0.9 \sin(4.2 \times 0.05t) + 0.05 \times randn, \quad (4)$$

where $randn$ is Gaussian random variable with zero mean.

The outlier maximum duration for the algorithm is set to 4 points while the last added outlier duration is intentionally made to be 5 points. Figures 1–4 present the steps of the algorithm.

Figures 5–6 present the interval of the initial data before and after outliers elimination. The last outlier duration of which was set to exceed the maximum eliminated outlier duration is preserved in the data.

Since the algorithm has been designed to eliminate random measurement errors maximum outlier duration of more than 4 points should not be set unless it is reliably known that the data in question contains long-duration outliers. Otherwise data without outliers might be undesirably modified.

Validation using simulated data has shown that the algorithm is capable of eliminating outliers of predefined duration with no additional unwanted changes made to the signal on the intervals without outliers.

3.2. Validation using actual WAMS data

It was outlined that outliers are inherent for the PMU data during transients. Thus disturbance WAMS data from PMUs installed on power stations in Russia was involved in algorithm validation. Figures 7–8 show the frequency recorded during a disturbance and outliers elimination result for this signal.

The outlier is clearly visible in figure 7 immediately after the disturbance. This outlier implies difficulties while identifying the low-frequency oscillations following after the disturbance. Automatic outlier elimination enables avoiding this effect.

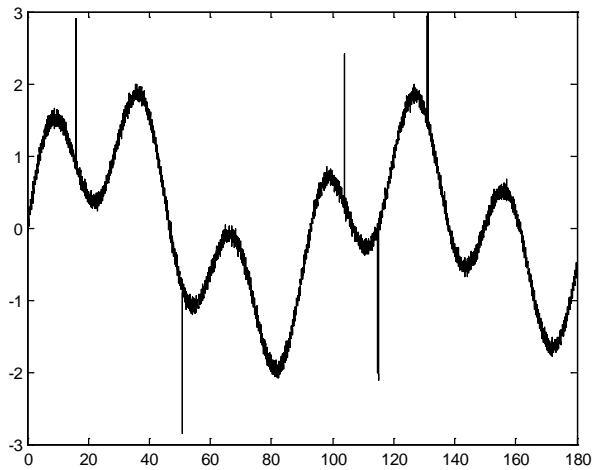


Figure 1. Simulated data.

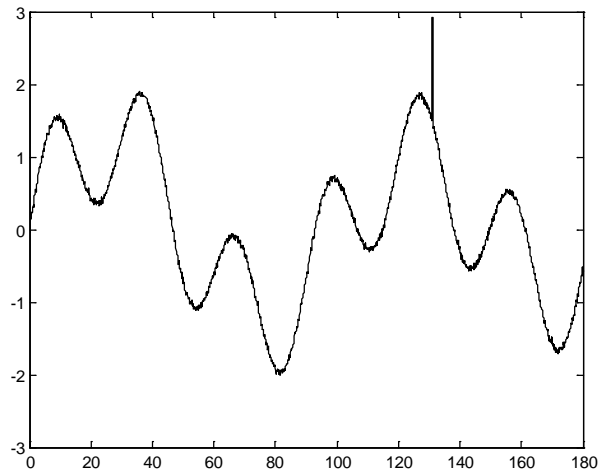


Figure 2. Filtering result.

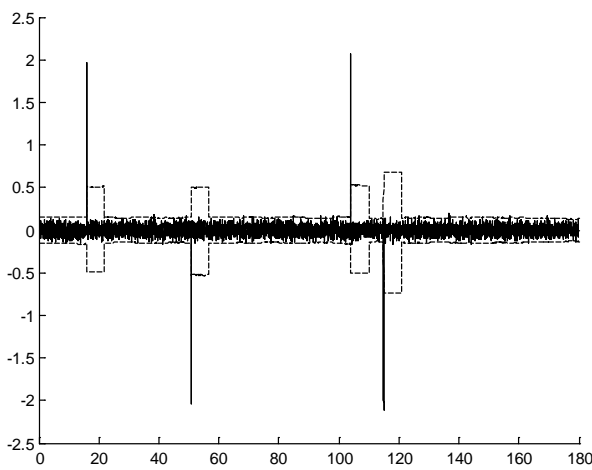


Figure 3. Difference between the initial data and the filtering result; $\bar{d} + 3\sigma_m$ (dash line).

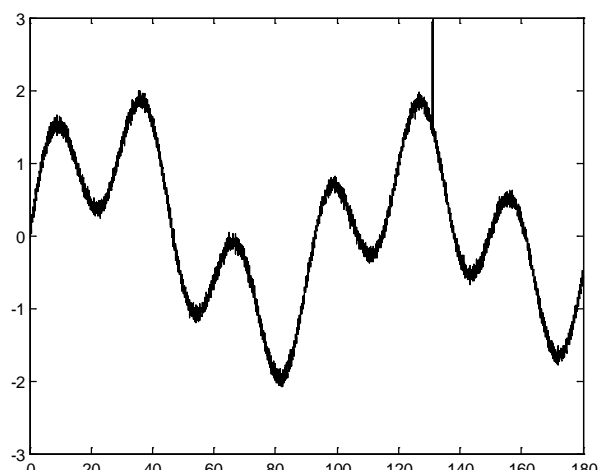


Figure 4. Outliers elimination result.

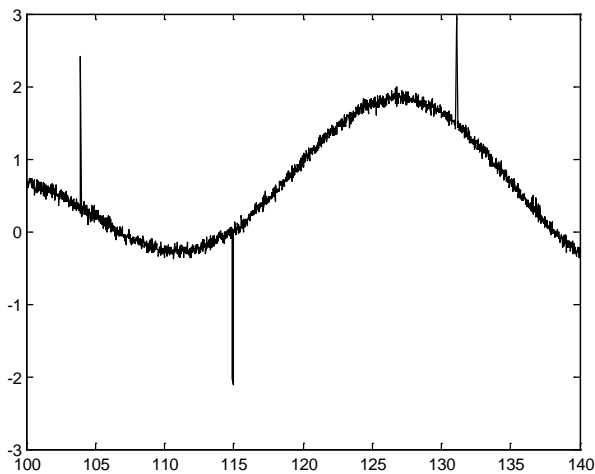


Figure 5. Initial data (interval between 100 s and 140 s).

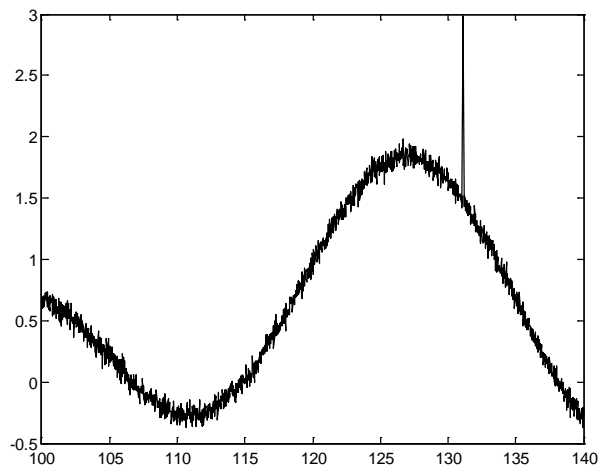


Figure 6. Outliers elimination result (interval between 100 s and 140 s).

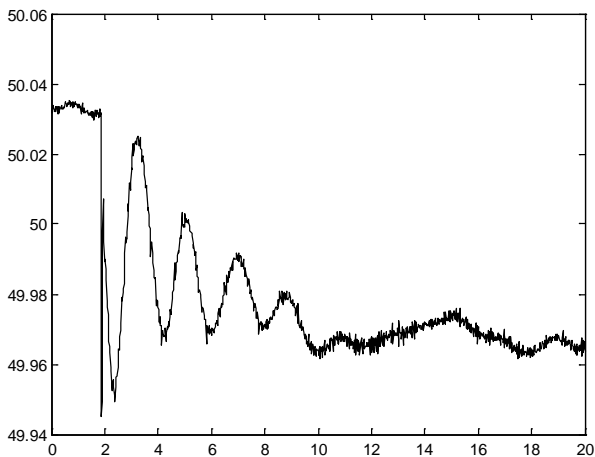


Figure 7. Actual WAMS data recorded after the disturbance.

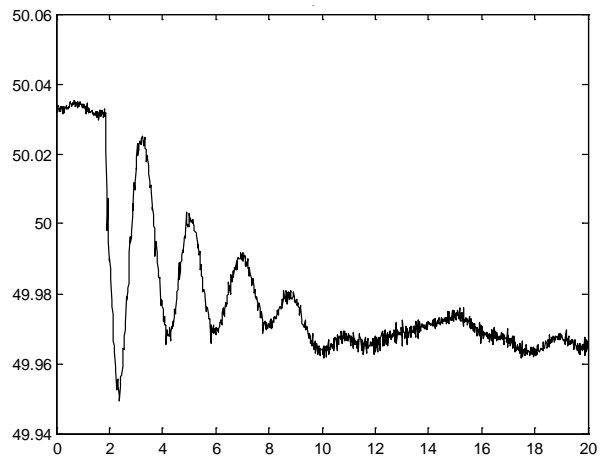


Figure 8. Outliers elimination result.

4. Conclusions

The algorithm is based on the concept of the irregular component of measurement signal for eliminating outliers has been developed for the purpose of data pre-processing before low-frequency oscillations automatic analysis and continuous monitoring. It has been proved to be effective and selective i.e. controlled by the adjustable parameter to the full extent. Since its application does not introduce significant calculations burden the algorithm may be implemented as a part of online monitoring tools.

5. References

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Acknowledgments

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